OBJECTIVES

1. Describe the basic operating principles of gas ionization detectors.

2. Describe the process involved in detection of radiation using scintillation detectors.

3. Describe the process of neutron detection using moderated BF_3 proportional counter.

4. Relate the concept of detector resolving time to considerations employed during the use of portable survey instruments.

5. Describe the operation of CARMs and the function they serve related to radiation protection.

6. Identify the various primary and supplemental dosimeters used at TJNAF.

7. Identify the following features and specifications for the listed portable instruments.

INSTRUMENT	FEATURES
Bicron Micro-rem	•Detector Type
"Teletector" Instruments	•Operating Ranges
NP-2, NG-2 (Snoopy)	•Detector Shielding/Window
"Frisker" Instruments	•Types/Energy of Radiation Detected
	•Location of Detector Center
	•Specific Limitations/ Characteristics

8. Identify the factors which affect the selection of a portable survey instrument.

9. State the calibration frequency requirements for portable survey instruments.

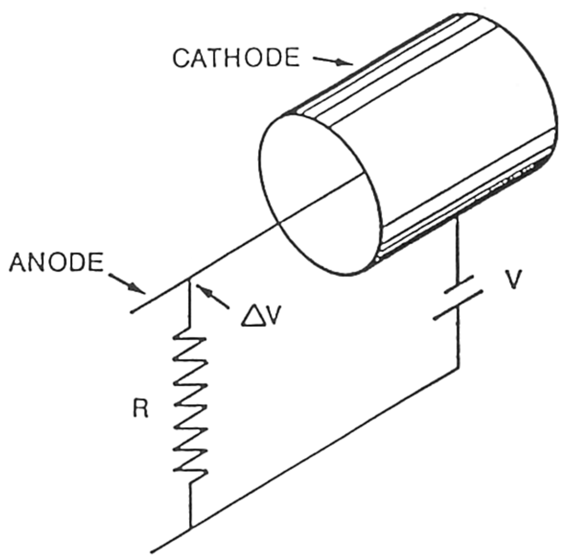
10. Describe the pre-use checks that must be performed when using portable survey instrumentation

GAS FILLED DETECTORS

Basic Construction

Any contained gas volume which has a pair of electrodes can serve as a gas filled ionization detector. These detectors are usually cylindrical. The cylinder wall is used as one electrode and an axial wire mounted in the center is used as the other electrode. Insulators support the axial electrode. The size, shape, and configuration is a function of the desired detector characteristics.

The gas used in the detector can be almost any gaseous mixture which will support ionization, including air. Some detectors, particularly ionization chambers use only air, while other detectors use gas mixtures that ionize more readily to obtain the desired detector response.



Two electrode, gas filled chamber

Detector Construction

For a gas filled ionization detector to be of value for radiological control purposes, the manner in which the response varies as a function of the energy, quantity, and type of radiation must be known. Factors such as the size and shape of the detector, the pressure and composition of the gas, the size of the voltage potential across the electrodes, the material of construction, the type of radiation, the quantity of radiation, and the energy of the radiation, can all affect the response of the detector. Detectors for a special purpose are designed to incorporate the optimum characteristics necessary to obtain the desired response.

Type and Energy of Radiation

Each type of radiation has a specific probability of interaction with the detector media. This probability varies with the energy of the incident radiation and the characteristics of the detector gas. The probability of interaction is expressed in terms of *specific ionization* with units of ion pairs per centimeter. A radiation with a high specific ionization, such as alpha, will produce many more ion pairs than will a radiation with a low specific ionization such as gamma. In Table 1, note the magnitude of the difference between the specific ionization for the three types of radiation.

Table 1. Specific Ionization In Air at STP.

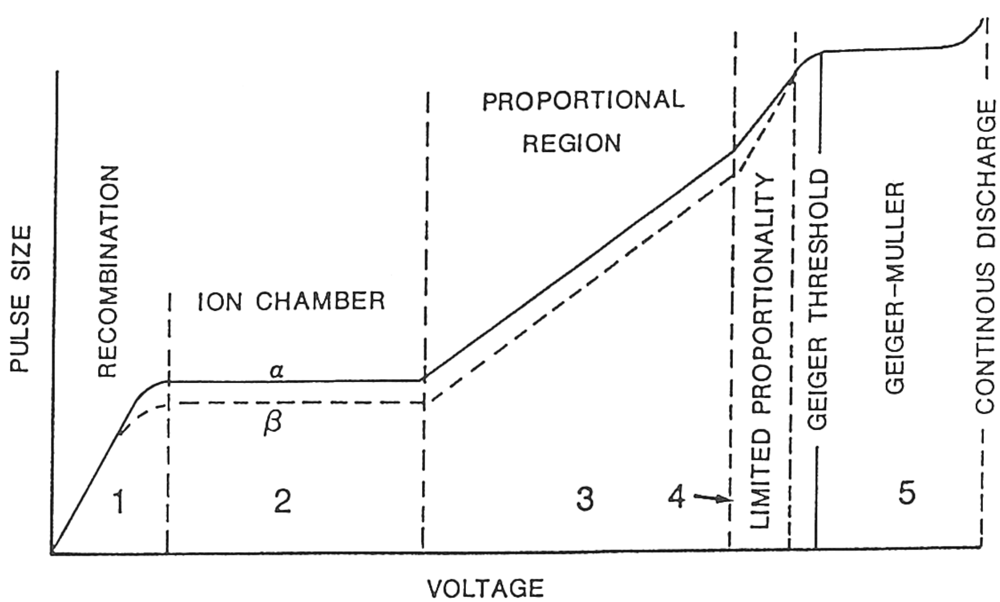
Radiation/energy	Ion pairs/cm
Alpha	
3MeV	55,000
6MeV	40,000
Beta	
0.5MeV	110
1MeV	92
3MeV	77
Gamma	
0.5MeV	0.6
1MeV	1.1
3MeV	2.5

Voltage Potential and Gas Amplification

Once the ion pair is created, it must be collected in order to produce an output pulse or current flow from the detector. If left undisturbed, the ion pairs will recombine, and not be collected. If an electric field is created in the detector by applying a voltage potential across the electrodes, the ion pairs will be accelerated towards the electrodes.

The stronger the field the stronger the acceleration. The accelerated ions may create secondary ionizations. The secondary ion pairs are accelerated towards the electrode and collected, resulting in a stronger pulse than would have been created by the ions from primary ionization.

If the applied voltage potential is varied from 0 to a high value, and the pulse size recorded, a response curve will be observed. For the purposes of discussion, this curve is broken into six regions. The ion chamber region, the proportional region, and the Geiger-Mueller region are useful for detector designs used in radiological control. Other regions are not useful. In the recombination region, the applied voltage is insufficient to collect all of the ion pairs before some of them recombine. In the limited proportional region, neither the output current nor the number of output pulses are proportional to the radiation level. Calibration is impossible. In the continuous discharge region, the voltage is sufficient to cause arcing and breakdown of the detector gas.



Pulse size as a function of bias voltage in an ionization chamber

ION CHAMBER DETECTORS

In the ion chamber region, there is an essentially equal number of ions collected as are created. No secondary ionization or gas amplification occurs. The output current of the detector will be proportional to the incident radiation intensity. Also, the output current will be relatively independent of small fluctuations in the power supply. An ion chamber is said to operate at “saturation”, because of the unity gas amplification factor.

Advantages

- Relatively low operating voltage. DC voltage from a battery supply is sufficient. Relatively insensitive to voltage changes within the operating voltage range.

- Since the ion chamber measures primary ion current, its response is a measurement of *exposure* (or normally, exposure rate). Ion chamber instruments normally read in units of mR or R/hr. If measuring a typical gamma radiation field, this translates into a reasonably accurate absorbed dose rate for tissue (recalling the conversion of R to rad), and hence to dose equivalent.

Disadvantages

- Detector output current is small. Independent current pulses large enough to measure are not formed by each ionizing event. Instead, the total current output created by many ionizing events is measured. Therefore, the sensitivity of a small ion chamber is very poor because a few ionizing events per minute do not create sufficient currents to be measured. A typical commercial portable ion chamber has a detector which produces a current of about 2 E-14 amps per mR/hr.

- Ion chamber instruments are sensitive to humidity, temperature and barometric pressure.

  Very high impedance circuits are used (approximately 1 E^{15} ohms) to measure the small output currents. Humidity creates current leakage which causes erroneous instrument response.

  Changes in barometric pressure (or altitude) and/or ambient temperature change the density of the air in the chamber and can affect instrument response. For instance, the response of a typical commercial portable ion chamber instrument decreases by 2% for each 10 degree increase in temperature, or decreases by 2.3% for each inch of mercury decrease in barometric pressure (4.6% per psi).

  To correct for these effects (collectively called "drift"), most ion chamber instruments employ a "zero" adjustment.

Typical Applications

Many portable dose rate survey instruments are ion chamber instruments. Ion chambers are also used in several installed monitor systems, such as the "slow beam loss" ion chambers.

PROPORTIONAL DETECTORS

In a proportional detector, the detector output pulse height is proportional to the total ionization produced in the detector.

As the voltage on the detector is increased beyond the ion chamber region, the ions created by primary ionization gain enough energy in the acceleration to produce secondary ionization. The secondary ions are also accelerated, causing additional ionizations. The large number of events (ion 'cascade') creates a single, large electrical pulse.

The gas amplification factors for typical proportional detectors range from a few hundred to about a million.

Proportional detectors are widely used in laboratory counting instruments. The total current and pulse magnitude, could be measured as is done with ion chamber detectors, but this is not usually done in proportional instruments.

In a proportional counter, high specific ionization radiations result in larger pulses. Since we can measure the individual pulse, it is possible to analyze both the rate of incidence and the relative energy with a proportional counter. This allows for discrimination of different types of radiation or different radiation energies by varying the high voltage (which affects the gas amplification factor) and employing a pulse height analyzer.

Resolving Time

After the ion avalanche occurs, it takes a finite time for the ions to be collected and for the pulse to be generated. Resolving time is the total amount of time following a measurable detector response before another pulse can be measured. In the proportional region, the resolving time is reasonably short, usually less than a microsecond. This resolving time does not lead to problems at low count rates, but can result in a considerable error at high count rates.

Proportional Counter Advantages

- A proportional counter can be used to discriminate between different types of radiation (using pulse height discrimination).
- A proportional counter output signal is larger and therefore a single ionizing event can be recorded (good sensitivity).
- When measuring current output, a proportional detector is useful for dose rates since the output signal is proportional to the energy deposited by ionization and therefore proportional to the true dose rate. Usually, they are operated in count rate mode with simple calibration of count rate to dose rate. Accuracy depends on calibration field energy in this case.

Proportional Counter Disadvantages

- A proportional counter is sensitive to high voltage changes because of the effect on the gas amplification factor. As a result, highly regulated power supplies are necessary for proportional counters. This may make the instrument larger or more expensive.

- Resolving time restrictions are usually not severe in a proportional detector unless count rates are very high (> E^6 cpm). Detector size can be used to compensate for this.

Typical Applications

Proportional counters find wide application in the industry. Gas flow proportional counters are commonly used for alpha/or beta counting on laboratory samples. Sealed proportional counters are commonly used for neutron monitoring, from portable neutron survey instruments to nuclear reactor neutron flux instruments. Some dose rate instruments (CARM) and field counting equipment (air monitors) utilize proportional detectors.

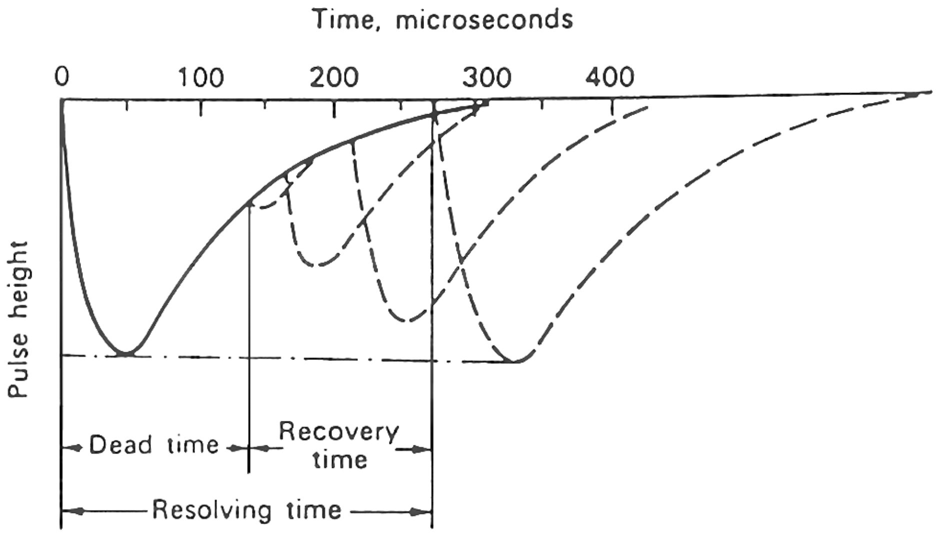
GEIGER-MUELLER DETECTORS

In a GM detector, voltage and detector gas combinations allow the ion cascade to grow into an "avalanche". In effect, an ion discharge occurs in the tube. This discharge, caused by a single ionization event, results in a single very large pulse. The electric field created by the produced ions essentially "cancels" the field created by the high voltage potential across the detector. When this occurs, the accelerating gradient decreases, preventing further secondary ionization and halting the avalanche.

In a GM tube, the gas amplification can range upwards to about $1E^8$. Since the tube is completely discharged with each event, the pulse size is uniform and independent of radiation energy or specific ionization (a 0.1 MeV gamma creates the same size pulse as a 0.01 MeV beta). For this reason, GM, tubes cannot discriminate against different radiation types or radiation energies.

Any radiation event with sufficient energy to create the first ion pair can create a large pulse. For this reason, the GM detector is more sensitive than the ion chamber or proportional counter.

A GM detector can also be avalanched by the small amount of energy released by a positive ion when it is neutralized at the cathode. To prevent this undesirable occurrence, a quenching gas is added to the counting gas. Thus, instead of causing ionization, this excess energy is expended in dissociating the quenching gas molecules. In effect, the quench gas acts as a low level discriminator, preventing counts from occurring from very low energy events. Without a quench gas, a GM tube would go into continuous discharge after the first ionizing event.



Relationship among dead time, recovery time and resolving time

Dead Time Considerations

In GM detectors, resolving time has greater impact on detector response.

Several effects are apparent due to the long resolving time of the GM detector.

- In a GM detector the ability of the detector to measure high dose rates accurately is reduced. For example, with a 200 μsec resolving time, a count rate of 10,000 cpm will be measured as 9,700 cpm, an error of 3%. At 100,000 cpm the measured count rate will be 75,000, an error of 25%. Many instruments have electronic dead time compensation circuits.

- Another effect in GM detectors is referred to as "paralyzation" of the tube. If the incident radiation events occur at an extremely high rate, a string of small pulses will occur. These pulses prevent the GM detector from completely recovering. Since a full size pulse does not occur, the electronics may not indicate that any radiation is present. Some instruments employ techniques to prevent paralysis.

- GM detectors must be used with caution around pulsed radiation sources. The operation of the GM tube is highly susceptible to tracking the pulse repetition rate of the radiation field, rather than the actual exposure rate. When surveying in a pulsed radiation field, an ion chamber should normally be used. Use of a GM detector should be limited to areas where pulse effects have been determined not to be a factor.

GM Detector Construction

GM detectors encountered in radiological control work are sealed cylindrical tubes. The geometry of the tube is a function of the intended use (eg. pancake). Many GM tubes employ beta windows– some with moveable window covers.

Advantages of GM Detectors

- GM detectors are relatively independent of the pressure and temperature effects which affect ion chamber detectors. This is because of the magnitude of the output pulse.

- GM detectors require less highly regulated power supplies. This is because the pulse repetition rate is measured and not the pulse height.

- GM detectors are generally more sensitive to low energy and low intensity radiations than are proportional or ion chamber detectors.
(There are exceptions.)

- GM detectors can be used with simpler electronics packages. The input sensitivity of a typical GM survey instrument is 300-800 millivolt, while the input sensitivity of a typical proportional survey instrument is 2 millivolt.

Disadvantages of GM Detectors

- GM detector response is not related to the energy deposited, therefore GM detectors can not be used to directly measure true dose (or exposure), as can be done with an ion chamber instrument.

- GM detectors have a typically large recovery time. This limits their use in extremely high radiation fields. Dead time can be reduced by reducing the physical size of the detector. However, the smaller the detector, the lower the sensitivity. For this reason, wide range GM survey instruments, such as the Teleprobe commonly have two GM detectors - one for the low ranges, one for the high ranges.

- GM detectors can not discriminate against different types of radiation (α, β, γ), nor against various radiation energies. This is because the size of the GM avalanche is independent of the primary ionization which created it.

- Detector paralysis and radiation pulse rate tracking are potential problems.

Typical Applications

GM detectors are widely used in portable survey instruments due to their ruggedness and the simplicity of the associated electronics. GM detectors are also used for personal monitoring for contamination (friskers), for process monitoring, and for area radiation monitoring. In addition, GM detectors are often used for laboratory counting when just a gross count is desired.

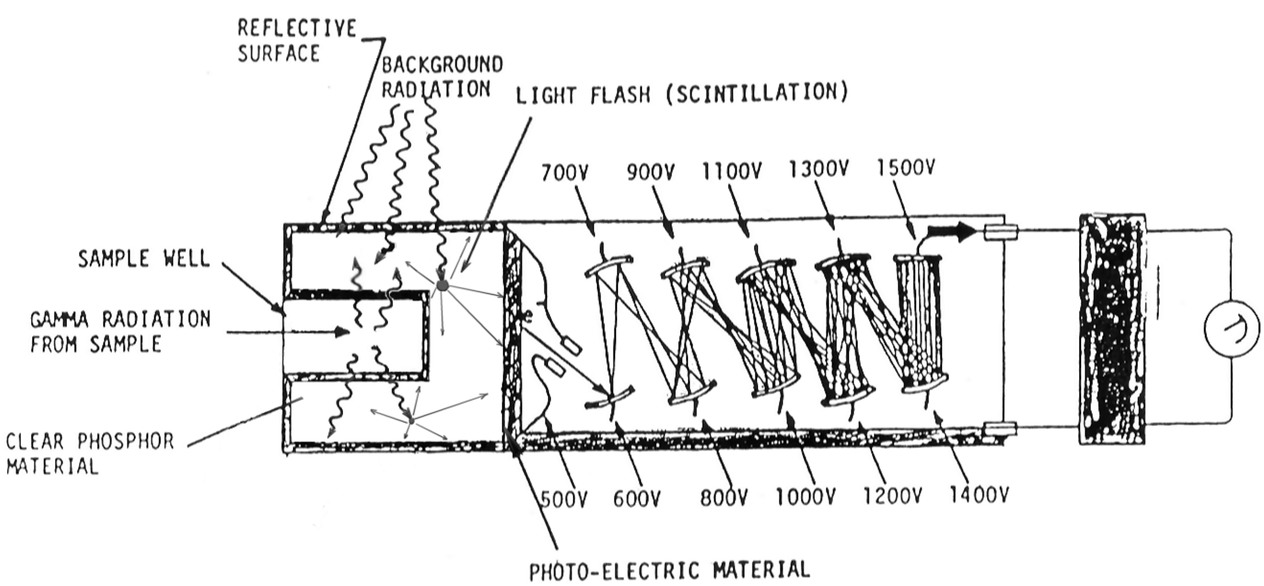
SCINTILLATION DETECTORS

Scintillation detectors measure radiation by analyzing the excitation of the detector material by the incident radiation. Scintillation is the process by which a material emits light when excited by radiation. In a scintillation detector, this emitted light is detected and measured to provide an indication of the amount of incident radiation. Numerous materials scintillate - liquids, solids, and gases. A material which scintillates is commonly called a phosphor or a fluor. The scintillations are commonly detected by a photo-multiplier tube (PMT).

Scintillation Detector Components

Phosphors of interest in field applications of scintillation detection are generally classified as either organic or inorganic, and are usually solids, or crystalline. The theory of operation, use, and response of these phosphors varies. The purpose of the phosphor is to convert the incident radiation to light.

Photomultipliers have several common, typical components. These common components are: the photocathode, the dynode assembly, an anode, voltage divider network, and shell. The PMT photocathode detects the light emitted by the phosphor, converts it to an electrical pulse which is proportional to the deposited energy from the incident radiation, the signal is amplified in the dynode string, often with amplification factors over 10^6. The voltage divider network provides a potential to each dynode stage.



Output

The photomultiplier tube provides an output pulse whose size is a function of the intensity of the light photons, and of the electron multiplication. Varying the HV to the photomultiplier varies the pulse height.

Advantages of Scintillation Detectors

- Ability to discriminate between alpha, beta, gamma radiations and between different radiation energies with a moderate resolution.
- Organics (plastic): Durable, have energy deposition characteristics similar to tissue.
- (NaI(Tl)): High gamma sensitivity. Fair resolution.
- (Liquid, usually organics): Good low energy response.
- (ZnS(Ag)): Good alpha detector. Poor resolution.

Disadvantages

- (NaI(Tl)): Usually no beta or alpha response, poor low energy gamma response due to encapsulation of crystal. Some special configurations allow this. Hygroscopic.
- (Liquid): Relatively cumbersome. Usually used to mix with samples. Solution is one time use only. Time consuming lab process.
- Requires stable power supply, MCA, ADC, etc. for pulse height analysis.
- (NaI(Tl) and ZnS(Ag)): Detector is not a solid state device, needs to be handled with care.
- Plastics: Poor energy resolution.
- PMTs are susceptible to high magnetic fields, RF. Fragile.

Applications

- Dose rate instruments/count rate meters (Microrem)
- Contamination monitors
- Laboratory instruments, spectrometers (LS Counting, gamma spec, neutron spec)
- Process/area monitors, environmental monitors

SPECIAL APPLICATIONS FOR NEUTRON DETECTION

Neutron detection often employs somewhat more complex techniques than other types. The energy of the radiation field and nature of neutron interactions in matter are important factors that must be addressed when attempting to assess neutron dose quantitatively.

Slow Neutron Detection

Absorption by Boron

Slow neutron absorption in boron is a common method used for neutron monitoring. When slow neutrons are absorbed by atoms of Boron-10, an alpha particle is emitted. This alpha particle produces ionization which can be measured. A detector may be lined with Boron-10 or filled with boron-trifluoride (BF_3) gas. These detectors are usually operated in the proportional region. Since the BF3 tube is also gamma sensitive, the instrument usually employs a pulse height discriminator to differentiate the large alpha pulse from the smaller photon induced pulses.

Fission Chambers

Slow (thermal) neutron absorption in U-235 can cause fission, with the two fission fragments produced having a high kinetic energy and causing ionization in the medium in which they are produced. The electrodes of an ion chamber may be coated with a thin layer of uranium enriched in U-235, creating a “fission chamber” which is sensitive to thermal neutrons.

A special type of fission detector called a fission track-etch detector is used at Jefferson Lab. These detectors serve as very sensitive neutron dosimeters which are used to monitor neutron exposure at the accelerator site boundary. A U-235 source is mounted adjacent to a special film. Fission events in the source liberate fission fragments, which create damage sites in the film. The foil is then etched in a chemical bath, and placed in an instrument that generates an arc through any etched site. These arc events are counted, and the number of sites is related to a dose through a calibration factor.

Scintillation

Scintillation detectors can be designed to detect slow neutrons by incorporating boron or lithium in the scintillation crystal. The neutrons interact with the boron or lithium atoms to produce an alpha particle, which then produces scintillation.

Slow Neutron Thermoluminescence

Thermoluminescent dosimeters can be designed to detect slow neutrons by incorporating lithium-6 in the crystal. This method is used frequently in TLD badges.

Activation Foils

Various materials have the ability to absorb neutrons of a specific energy and become radioactive through the radiative capture process. By measuring the radioactivity of thin foils such as gold, silver or indium, we can determine the amount of neutrons to which the foils were exposed. Commercially available criticality accident dosimeters often utilize this method.

Fast Neutron Detection

Proton Recoil (Ion Chamber/Proportional)

When fast neutrons undergo elastic scattering with hydrogen atoms, they frequently strike the hydrogen atom with enough force to knock the proton nucleus away from the orbiting electron. This energetic proton then produces ionization which can be measured. Most devices for measuring fast neutrons use an ionization detector operated in either the ion chamber or proportional region.

Thermalization (Slowing Down Fast Neutrons)

There are several methods for detecting slow neutrons, and few methods for detecting fast neutrons. Therefore, fast neutron monitoring usually involves “moderating” the energy of the fast neutrons, and detecting the slow neutrons. In this technique, the moderator is placed around the detector to “thermalize” the neutrons, which are then detected as above in the slow neutron detector.

PASSIVE MONITORING

Thermoluminescent Dosimeters (TLD)

Thermoluminescence is the ability of some materials to convert the energy from radiation to a radiation of a different wavelength, normally in the visible light range. In the case of the TLD, this emission of light is not instantaneous or spontaneous, but must be stimulated by the addition of heat energy.

In TL material, electrons are disrupted by ionization/excitation and moved into elevated energy states. The electrons are 'trapped' in normally unoccupied energy bands by doped impurities in the crystal.

These trapped electrons represent stored energy for the time that the electrons are held. This energy is given up if the electron returns to the valence band.

TLDs can be used to measure beta, gamma, and neutron radiations. At Jlab, neutron dose is also measured by a device known as a neutron track-etch dosimeter (similar to a fission track-etch device). The neutron response of the TLD is very sensitive to the energy of the neutron field. In cases where the neutron energy is well known, neutron factors can be established to accurately determine neutron dose from TLDs. The track etch element has a fairly flat response to higher energy neutrons. The response from both elements is evaluated to determine the dose.

ADVANTAGES AND DISADVANTAGES OF TLDs

Advantages (primarily as compared to film badges)

- Able to measure a greater range of doses
- Response is linear
- Readout can be automated, and is very accurate if calibrated properly
- They can be read on site instead of being sent away for developing
- Quicker turnaround time for readout
- Reusable

Disadvantages

- Cannot be read out more than once (for a given dose) - the readout process effectively "zeroes" the TLD.
- The result is not a "physical" record, as with film, but the readout parameters are stored electronically

Also used at Jefferson Lab in conjunction with the TLD, is the track-etch neutron dosimeter. The track-etch dosimeter is responsive to fast neutrons in a direct way. The neutrons which interact in the material of the dosimeter (a poly-carbonate plastic) leave microscopic damage sites. Etching of the material following exposure allows the sites to be viewed under a microscope and counted. The number of sites (tracks) is related to the absorbed dose.

Supplemental Dosimeters

In addition to TLDs, a number of supplemental dosimeters are used at Jefferson Lab. The term Self-Reading Pocket Dosimeter (SRPD) is used to describe any type of dosimeter that displays dose information directly to the user. At Jlab "SRPD" is usually used to describe the Pocket Ion Chamber (PIC). Along with the PIC are the digital alarming dosimeter (often called DAD or ED), and the neutron bubble dosimeter.

- Pocket ion chambers (quartz fiber electroscope) are small air-filled ion chambers. A charge of approximately 200 volts is placed on the chamber by the charger. The positive charge is distributed on the wire electrode and quartz fiber. The moveable quartz fiber is repelled from the wire electrode since like charges repel. As air in the chamber is ionized by radiation, the electrons migrate to the fiber and electrode, reducing it's positive charge. Since the charges on the electrode and the fiber are lessened, the fiber moves back toward the electrode. This is the "hairline" seen when looking through the SRPD. Anything that can adversely affect the response of an ion chamber can affect the response on a self-reading dosimeter.

- Digital dosimeters are sometimes used instead of and in addition to SRPDs when it is helpful to have he additional capability of dose or dose rate alarm functions. Digital dosimeters used at Jlab are actually small GM survey meters which integrate exposure. Because of the drawbacks of GM tubes, digital dosimeters should not be used around pulsed radiation fields without other means to evaluate the radiation field.

- Neutron bubble dosimeters contain a gel which holds a superheated liquid drop matrix. When neutrons interact in these superheated drops, the drops are vaporized by the deposition of the energy. The visible bubbles are counted and a calibration correction factor is applied to obtain the dose.

FIXED RADIATION MONITORING INSTRUMENTATION

Stationary instruments are used to provide indication of area radiation levels, provide a record of area dosimetry for ALARA purposes and for protective trip functions where they prevent situation which could cause persons to exceed certain dose limits. These instruments are used by the RCG staff and are not available for use by ARMs or others for radiation control functions except under the direct authorization and instruction of the RCG.

Types of stationary instruments used include:

- Controlled Area Radiation Monitor (CARM) ADM-610 & ADM-616
    - ~ 50 monitors in accessible areas near beam enclosure (some units also in Test Lab at Cryo-test cave)
    - Photon (proportional) and neutron (BF-3) channel
    - Visible and audible alarms
    - Interlocked to PSS to trip on high alarm and power loss
    - Nominal trip point in RCA is 2 mrem/hr
    - Readout through MEDM screens
- Boundary Monitors (RBMs) ADM-600
    - Six units located at site boundary
    - Photon (GM) (some have scintillators) and neutron (He-3) channel
    - Readout through MEDM screens (not PSS interlocked)
- Others – Eberline RMS-II
    - VTA and at beam dump cooling water buildings
    - VTA units are interlocked to PSS, data logged
    - Beam dump building units have feedback to MEDM (not interlocked)

The RCG may as ARMs for their assistance in relocating fixed instrument detectors, visually checking the status of CARMs, operational/functional testing, and other periodic surveillance of the equipment. This is usually done in accordance with a commissioning test plan, TOSP, or other documented procedure. In addition, the ARM may respond to a trip of an interlocked CARM. Procedures for alarm response are covered in a later section.

PORTABLE SURVEY INSTRUMENTS
Types available and their applications

Bicron Microrem
Detector Type - Plastic (tissue equivalent) scintillator
Radiation Detected - Photon
Readout - Analogue, microrem/hr
Range - Up to 200 mrem/hr in five scales
Uses - Area surveys, entry to tunnel after shutdown, item release surveys
Specific Limitations - Response falls off in magnetic field

Teleprobe (FAG) (extendable survey meter)
Detector Type - GM (2 tubes) with dead time correction
Radiation Detected - Photon (some have beta window)
Readout - Digital, auto-ranging
Range - Up to 1000 R/hr (hand held base unit goes to 1 R/hr)
Uses - Area surveys, good for reaching in overhead or getting distance from high dose rates
Specific Limitations - Pulse sensitive, accuracy poor at background levels

Nuclear Research ADM-300x (extendable survey meter)
Detector Type - GM
Radiation Detected - Photon (has beta window, but not calibrated for beta)
Readout - Digital autoranging
Range - Up to 10,000 R/hr
Uses - Area surveys, good for reaching in overhead or getting distance from high dose rates
Specific Limitations - Pulse sensitive, accuracy poor at background levels

Nuclear Research ADM-300 (base unit)
Same as above, without extension
Uses – “Special re-sweep” procedure (used as an alarming dose rate meter)

Nuclear Research NP-2 and NG-2
Detector Type - BF-3 Proportional (NG-2 also has GM tube for gamma)
Radiation Detected - Neutron (NG-2 also sees photons)
Readout - Analogue (NP-2) Digital (NG-2) microrem or millirem per hour
Range - Calibrated up to 100 mrem/hr
Uses - Area neutron dose rates, NG-2 has dose logging, dose integrator
Specific Limitations - Very slow response, response not well characterized above ~10 MeV

Ludlum-3 and others with "Pancake Probe" (includes A/C powered versions)
Detector Type - GM
Radiation Detected - Beta, gamma (sees alpha, but not calibrated)
Readout - Counts per minute
Range - Up to 500 k cpm in four or five scales
Uses - Surface contamination surveys either direct or on swipes, some activation surveys
Specific Limitations - Relies on proximity to surface, gamma sensitivity low, dead time

SELECTION AND USE OF PORTABLE RADIATION INSTRUMENTATION

Measurements using portable radiation survey instruments provide the basis for assignment of practical external exposure controls. In order to establish the proper controls, radiation measurements must be an accurate representation of the actual conditions.

Many factors can affect how well the measurement reflects the actual conditions. These include:

- Selection of the appropriate instrument
- Correct operation of the instrument based on its characteristics and limitations
- Calibration of the instrument to a known radiation field similar in type, energy and intensity to the radiation field to be measured.
- Other radiological and non-radiological factors such as radioactive gases, mixed radiation fields, humidity, temperature, and the presence of electromagnetic fields.

Once the proper type of instrument has been identified, a pre-operational check is essential and must be performed in accordance with appropriate procedures.

Pre-use Checks

1. Physical inspection for obvious defects or damage that would render the instrument unusable.

2. Ensure that the instrument is within its calibration period. **For portable instruments, the calibration frequency is semiannual.**

3. **Check for a current response check. All portable instruments must be source checked at routine intervals to ensure operability. If the response check is overdue (indicated by a dated label on the instrument), DO NOT USE THE INSTRUMENT.**

4. Perform a battery check. Most instruments have a battery check position or pushbutton battery check. If the instrument does not respond properly to the battery check, <u>do not use it - remove it from service and tag it for repair.</u> (Changing batteries is permitted on most instruments)

5. If appropriate, perform a zero adjustment for the meter. This is common on ion chambers.

6. On instruments that respond at background dose rates, select the lowest range and verify proper response to the background.

If any of the pre-use checks are not satisfactory, DO NOT USE THE INSTRUMENT

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References for Unit 3

1. *Operational Health Physics Training*, Moe, ANL-88-26, 1988.

2. *The Health Physics and Radiological Health Handbook,* Shleien, 1992.

3. TJNAF Radiological Control Manual, Jan 1, 1994

4. DOE Standardized Training for Radiological Control Technologists, May 1994

5. *Introduction to Health Physics,* Cember, 1983

OBJECTIVES

1. List the criteria for posting Radiologically Controlled Areas, Radiation Areas, and Hot Spots.

2. Describe administrative and physical area controls required for Radiation and High Radiation Areas.

3. State the requirements for entering, working in, and exiting High Radiation Areas.

4. Describe area controls and access requirements for contaminated areas.

5. Describe the use of Radioactive Material Tracking Forms and RCOPs.

6. Describe the process of RWP initiation.

7. State the conditions requiring an RWP.

8. Identify the correct responses to radiation alarms, spills and emergencies.

ADMINISTRATIVE CONTROLS

Radiological Postings

Definitions:

Whole Body Dose rate measurement made 30 cm from a radiation source or a surface through which radiation penetrates.

Whole Body As applied to personnel dose, a dose from penetrating radiation (deep dose) received by any part of the whole body - that is - the head and trunk, arms extending to the elbows and legs extending to the knee.

General Area Taken to be approximately one meter from a radiation source or in the generally accessible area or walkway/work area.

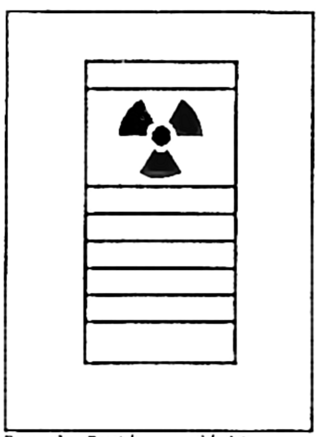
Contact Within an inch of a radiation emitting surface or item.

Signs and Boundaries

Postings (signs, labels, etc.) and identifiable boundaries (such as fences, doors, and ropes) are used extensively in radiation protection work to communicate radiological conditions to personnel. Since radiation and contamination are not detected by the senses, these administrative controls are the only method available to communicate these conditions in the absence of the full-time presence of personnel or monitoring systems to perform this task. It follows that these administrative controls must be used in a consistent fashion and must follow strictly prescribed rules for use.

In the absence of doors or other physical entry points, yellow and magenta rope, tape, chains or other barriers are used to designate the boundary. The boundary must be placed where the dose rate is less than or equal to the trigger for the posting.

Specific requirements for postings are found in 10CFR835 Subpart G. Jlab-specific signage protocol is shown here.



Example Posting - slight variance permitted with RCO concurrence.

INSERT HIERARCHY

Insert Section 1 - Hazard Level

Insert Section 2 - Hazard Type
Insert Section 3 - Area Modifiers
Insert Section 4 - Notifications or other postings

NOTES:

1. Section 1 shall be used for identifying the hazard level, (i.e. Caution, Danger, Grave Danger).
2. Section 2 shall be used for the area hazard type (i.e. Controlled, Contamination, etc.) only. The only exception for this section is to avoid double posting.
3. Section 3 - Area Modifiers refers to the secondary postings required in some areas. For example, if an "Airborne Radioactivity Area" was being posted, the modifier could be "Contamination Area". If no area modifications are required, place Section 4 requirements in this section.
4. Section 4 - Place informational inserts here.

Required Hierarchy of Area Postings

AREA DEFINITIONS AND POSTINGS

CONTROLLED AREA

An area to which access is controlled in order to protect individuals from exposure to radiation and radioactive materials is known as a Controlled Area. It is a boundary area around other radiological areas. The Jlab accelerator site (fenced in area bounded by locked or guarded access gates) has been designated as a **Controlled Area**.

Controlled Areas are administratively determined by the RCG. The ARM is not expected to determine or designate Controlled Areas.

RADIOLOGICALY CONTROLLED AREA

Areas where personnel may receive more than 100 mrem in a year are posted as RCAs. **In the absence of specific occupancy factors, this area must be posted when the whole body dose rate exceeds 0.05 mrem/hr.** The posting hierarchy for the RCA is as follows:

•Hazard Level = CAUTION (Hazard level is optional on RCA)

•Hazard Type = Radiologically Controlled Area or Radiological Area

•Area Modifiers = If the RCA contains radioactive material, this will be included

•Notifications = Dosimetry required for entry

Example Posting:

**RADIOLOGICALLY
CONTROLLED
AREA**

RADIOACTIVE MATERIALS

**DOSIMETRY REQUIRED
FOR ENTRY**

<u>RADIATION AREA</u> - Areas where the *whole body* radiation dose rate is $\geq$5 mrem/hr but <100 mrem/hr.

- Hazard Level = CAUTION
- Hazard Type = Radiation Area
- Area Modifiers = Any secondary area postings such as "Contamination Area"
- Notifications = Usually, Radiation areas require at least RCG concurrence for work. If trigger values are exceeded, "RWP Required" is posted (we will discuss triggers later).

A rope or other indication of the boundary is necessary. At a minimum, stanchions with signs attached can be used to provide this boundary, but they must be placed frequently, and be visible from any angle of approach.

<u>HIGH RADIATION AREA</u> - **Areas where whole body radiation dose rates are $\geq$100 mrem/hr.**

- Hazard Level = DANGER
- Hazard Type = High Radiation Area
- Area Modifiers = Any secondary area postings such as "Contamination Area"
- Notifications = "RWP Required" Others such as "Supplemental dosimetry required" are optional.

NOTE: ARMs are not normally expected to post or survey High Radiation Areas. However, suitable access controls and/or postings and barriers should be instituted pending RCG assistance.

<u>Hot Spot</u> - A spot (usually small) where the dose rate on contact is **greater than 100 mrem/hr and at least five times the whole body dose rate**. The contact dose rate is written on the Hot Spot label.

Note: Hot Spots found during a survey by an ARM may not require posting if other administrative controls are in place. This will be covered more in the survey practices section.

Summary of areas

Location	Dose Rate Criteria	Posting
Controlled Area	< 100 mrem/yr	'Controlled Area, Training or Escort Required for Entry'
Radiologically Controlled Area	> 0.05 mrem/hr (>100 mrem/yr)	'Radiologically Controlled Area, (or 'RCA') Dosimetry Required for Entry'
Radiation Area	5 mrem/h - 100 mrem/h	'Caution Radiation Area, TLD Required'
High Radiation Area	0.1 rem/h - 5 rem/h	'Danger High Radiation Area, RWP Required'
Hot Spot	> 0.1 rem/h on contact	'Caution Hot Spot'

In addition to these areas, several other designations are used, and should be understood by ARMs, although the ARM is not expected to determine the posting requirements for them.

- Contamination Area – posted when measured or suspected loose surface contamination levels are above 1000 dpm/100 cm^2 (for beta-gamma emitters).
  - Requirements for entry include
    - RWP
    - PPE
    - RW-II training

- Very High Radiation Area – Jlab designates VHRA as any area with a whole body dose rate greater than 5 rem/hr. (The DOE definition is less conservative)
  - Special access controls are required to prevent unauthorized entry
  - Entry/work in the area would likely cause individuals to exceed the site administrative dose control level, so access is normally not permitted. Emergency entry allowed with senior management approval.

- Airborne Radioactivity Area – an area in which airborne concentrations of radioactive material exceed or may exceed the Derived Air Concentration (DAC) values listed in part 835, or in which a person could receive an intake of 12 DAC-hrs in a week.
  - Requirements for entry **
    - RWP
    - RW-II training
    - Respiratory protection training
    - RP equipment

** These requirements apply when the hazard is due to airborne particulates. RP equipment is not automatically imposed in airborne areas, but is used based on an ALARA assessment. No special access controls are necessary when the hazard is due only to gaseous activation products. Parts of the accelerator enclosure are posted airborne radioactivity areas due to N-13 and other activation gases.

Administrative Work Controls

RADIOLOGICAL WORK PERMITS (RWP)

10CFR835 requires "written authorization" for entering and performing work in radiological areas. Jefferson Lab typically implements this requirement through the use of RWPs. The DOE definition of "radiological area" includes Radiation, High Radiation, Contamination, and Airborne Radioactivity areas. For accelerator enclosure RCAs, part 835 requirements are met by the use of a General Access RWP. This RWP applies to general work and imposes "hold points" where further evaluation is required. When controls beyond the scope of the General Access permit are needed, a Job Specific RWP will be issued. If the Job Specific RWP covers a repetitive or ongoing task, it may take the form of a Standing RWP, which may be authorized for up to one year.

Standard triggers for Job Specific RWPs are as follows:

- Entry into High Radiation Areas
- Work in areas where whole body dose rates exceed 25 mR/hr.
- Anticipated dose to a worker of 25 mrem in a shift.
- Work on a component that measures >250 mR/hr on contact.
- Entry into Contaminated Areas, or work that may generate contamination
- Entry into an Airborne Radioactivity Area (where hazard is inhalation, not immersion)

RWPs may also be used at the discretion of the RCG to control work in other radiological areas where appropriate. Examples may be when machining radioactive components or during radiography.

The PROCESS of RWP generation

- Should be initiated by the work group anticipating the need for access or work
- For General Access RWPs the RCG will issue the RWP when it is evident entry is necessary

Purpose of an RWP (Note: RWPs may be required in addition to OSPs, RCOPs, etc.)

- Inform workers of area radiological conditions.
- Inform workers of entry requirements into the areas.
- Provide access control for radiological areas.
- Provide a means for dose tracking and work history documentation

<u>Entry Requirements for Radiation and High Radiation Areas</u>

Radiation Areas

- Radworker I training (minimum)
- Read, understand, and sign in on the appropriate RWP
  (in beam enclosures, entry to areas up to 25 mrem/hr may be permitted with RCG concurrence under provisions of the General Access RWP)
- TLD (supplemental dosimetry required in accordance with dose rate triggers above)
- Radiation survey prior to entry after any operation that may have changed the conditions in the area
- Concurrence from RCG representative

High Radiation Areas

- Radworker I training (minimum)
- Read, understand, and sign in on the appropriate RWP
- TLD and supplemental dosimeter
- Radiation survey prior to entry after any operation that may have changed the conditions in the area
- Concurrence from RCG representative

Additional requirements when dose rates are > 1000 mrem/hr.

- Formal radiological review of non-routine or complex work
- Determination of the worker's current dose
- Documented pre-job briefing
- Continuous RCG coverage
- Dose rate indicating device and/or alarming dosimeter
- Physical access controls, as outlined below

PHYSICAL ACCESS CONTROLS FOR HIGH AND VERY HIGH RADIATION AREAS

1. One or more of the following features shall be used for each entrance or access point to a high radiation area where radiation levels exist such that an individual could exceed a deep dose equivalent to the whole body of 1 rem in any one hour at 30 centimeters from the source or from any surface that the radiation penetrates:

   a. A control device that prevents entry to the area when high radiation levels exist or upon entry causes the radiation level to be reduced below that level defining a High Radiation Area

   b. A device that functions automatically to prevent use or operation of the radiation source or field while personnel are in the area

   c. A control device that energizes a conspicuous visible or audible alarm signal so that the person entering the High Radiation Area and the supervisor of the activity are made aware of the entry;

   d. Entryways that are locked, except during periods when access to the area is required, with positive control over each entry

   e. Continuous direct or electronic surveillance that is capable of preventing unauthorized entry;

   f. A control device that will automatically generate audible and visual alarm signals to alert individuals in the area before use or operation of the radiation source and in sufficient time to permit evacuation of the area or activation of a secondary control device that will prevent use or operation of the source. Prior to operation of the accelerator:

      1. An announcement indicating that a tunnel sweep will commence within a certain period of time

      2. A sweep (physical search) of the accelerator enclosure which requires a sequential key activated enabling of Run/Safe boxes. Run/Safe boxes visually indicate accelerator state and allow for emergency shut down of the accelerator

      3. A second announcement indicating that radiation producing activities will begin in the enclosure followed by a dimming of the enclosure lighting

   g. In addition to the above requirements, additional measures shall be implemented to ensure that individuals are not able to gain unauthorized or inadvertent access to Very High Radiation Areas.

   h. Physical access controls over High and Very High Radiation Areas shall be established in such a way that does not prevent a person from leaving the area.

Practices during work in Radiation and High Radiation Areas

- Don't loiter
- Stay in designated low-dose rate areas when not immediately involved in the work
- Strict observance of stay time limits and other requirements of the RWP
- In the event of dosimeter alarm, malfunction, or anomaly
    - Stop work
    - Alert others
    - Exit the area immediately
    - Notify the RCG
- When exiting:
    - Observe all posted or RWP requirements for frisking
    - Have any equipment removed from the area surveyed prior to removal
    - Complete the RWP log entry

RADIOLOGICAL CONTROL OPERATING PROCEDURES (RCOP)

RCOPs are used for controlling work which may produce changing radiation levels such as operating Radiation Generating Devices (RGDs) or other tasks involving direct manipulation of radiation sources or radiological equipment.

Typical applications include:

- Operation of accelerator components or other RGD in an unshielded, unusual, or temporary configuration
- X-ray tubes or machines
- Use of radioactive material in an industrial process
- Use of sealed sources that may produce a Radiation Area
- Special commissioning tests or configurations

RADIOACTIVE MATERIAL CONTROLS

If a survey indicates that an item requires classification as radioactive material, it must be stored in a Radiologically Controlled Area. Unless the item is part of installed beamline hardware, it should be labeled as radioactive material. If it is necessary to remove the item from the RCA, the following requirements apply.

- A radioactive material tag or appropriate label must be affixed.
- An approved, properly labeled storage area will be designated for the material.
- If the dose rate from the item exceeds the level delineating a RCA, the storage area must be posted as such.
- When radiation levels allow, the item may be stored outside an RCA. When this occurs, a Controlled Material Tracking Form is attached. If the item leaves the Site Controlled Area, the form serves as the Controlled Area posting.
- A custodian for the material will be designated and identified on the CMTF.

EMERGENCY RESPONSE PROCEDURES

The ARM is expected to respond appropriately to the following potential scenarios

- CARM alarms
- Loss or damage to radioactive materials or sources
- Injured person in a radiological area
- Direct beam exposure accident

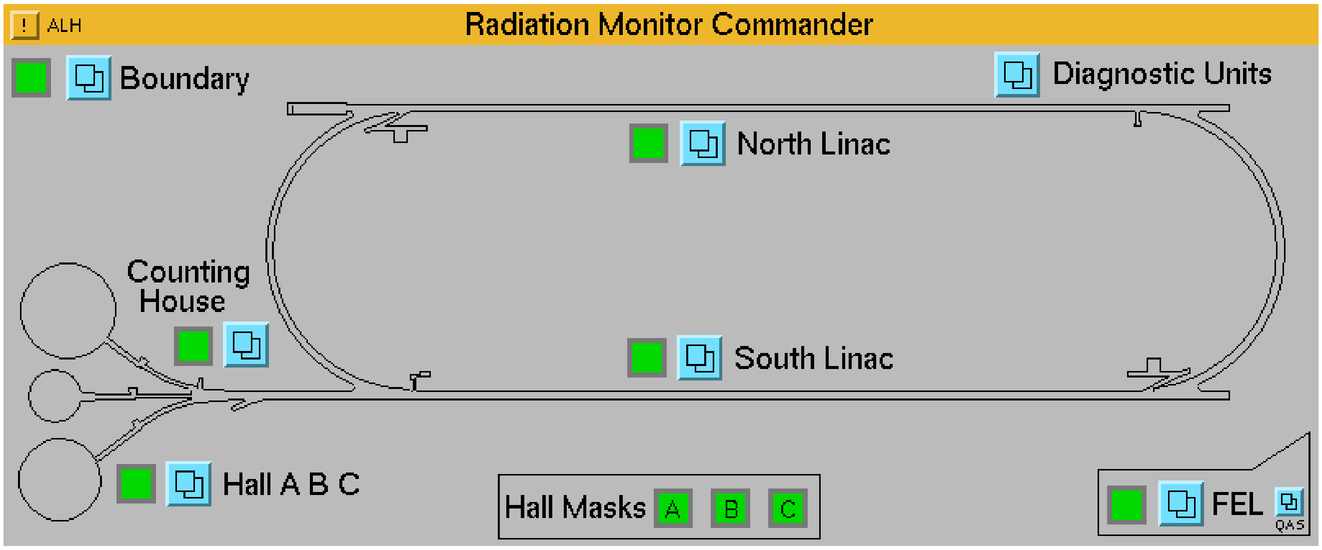
General Guidelines

CARM ALARMS

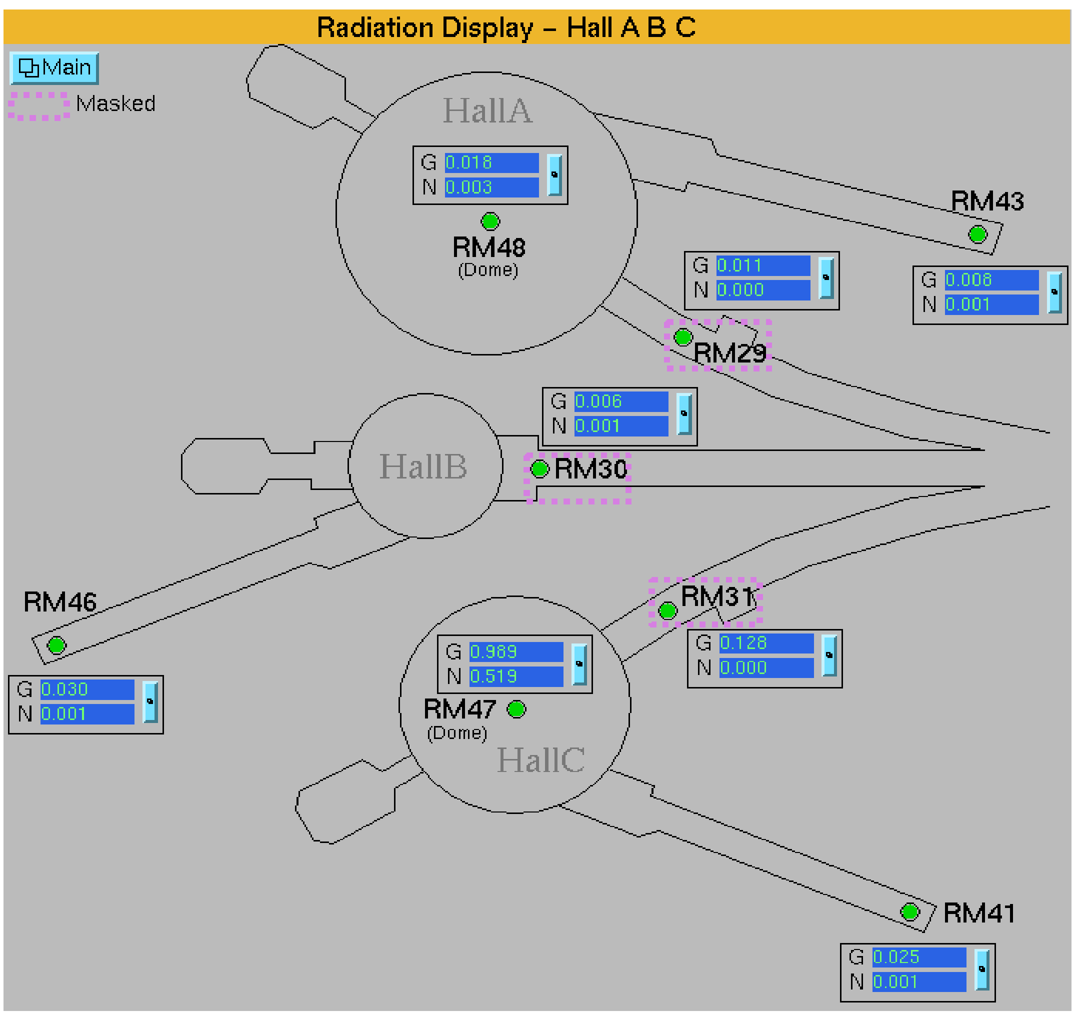
- Ascertain location of the CARM
- Observe the current readings (screen captures may be helpful for elog purposes).
- If the condition caused an accelerator trip (High Alarm), verify that the dose rate is not sustained. Acknowledge the alarm if necessary. The alarm will reset in no more than 30 seconds once the condition has stopped. An alarm that continues longer than this indicates either the radiation condition still exists, or the unit has failed. The alarm can be acknowledged if necessary.
- Write an Ops-PR for the event – do not check "requires further attention". If the unit causes a second trip, investigate further to see if cause can be isolated and call the RCG with all available information.
- In the case of an "Alert" alarm (no trip), again check the dose rate, and if necessary acknowledge the alarm. If the dose rate is sustained, display the output of the unit on the datalogger. If the display indicates long term (significant portions of an hour) sustained dose rates above the alert threshold, and operational adjustments do not correct the condition, call the RCG. Write an Ops-pr, same as above, even if unit returns to normal quickly.
- DO NOT relocate the probes or attempt to reset the alarm levels of the CARM without specific authorization from RCG.
- Once resolved, if an alarm condition reoccurs, call the RCG

NOTE: Communications failures on CARMs do **NOT** cause the accelerator to trip. If there has been a trip of the machine which appears CARM-related, and the screen indicates a comm. failure, that is not the cause of the alarm, however, the failed comm. link may have been *caused* by the same root condition that caused the trip.

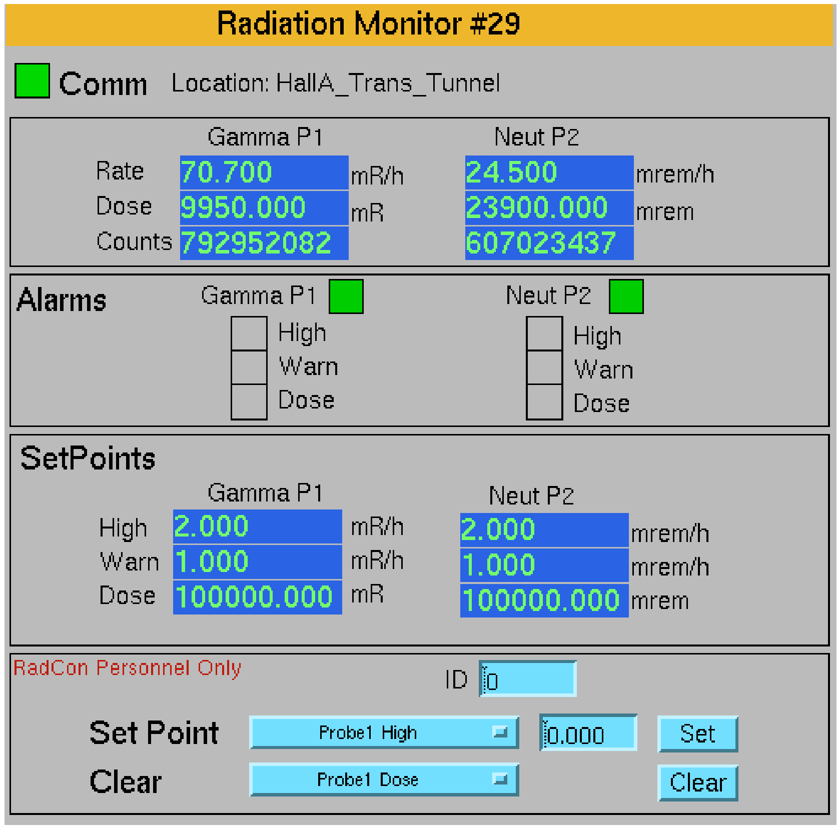
Radiation Monitoring on MEDM



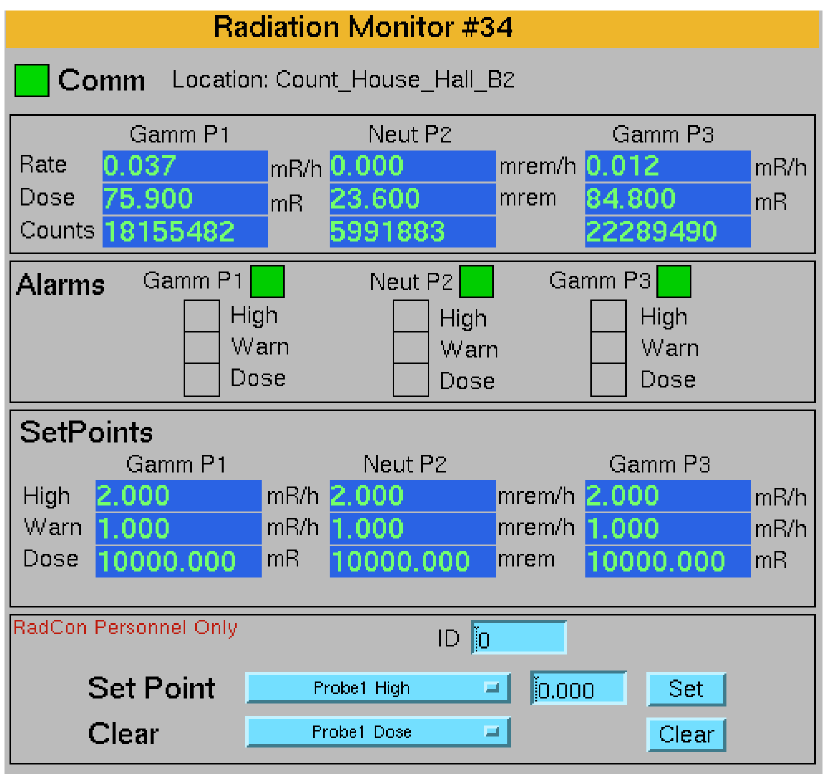
Main view



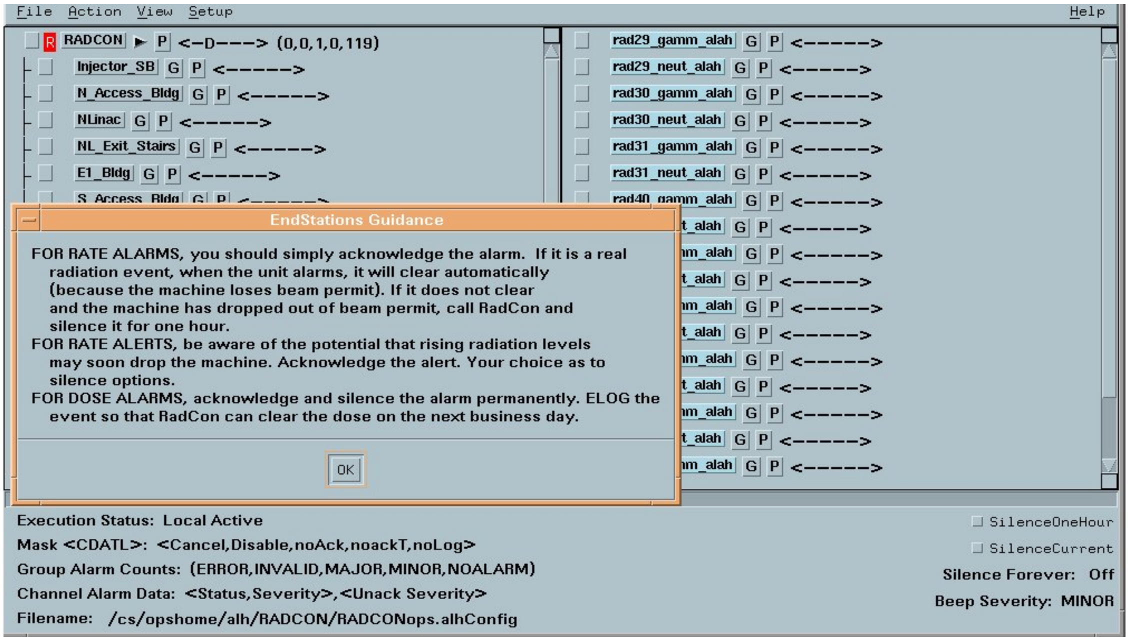
Halls view



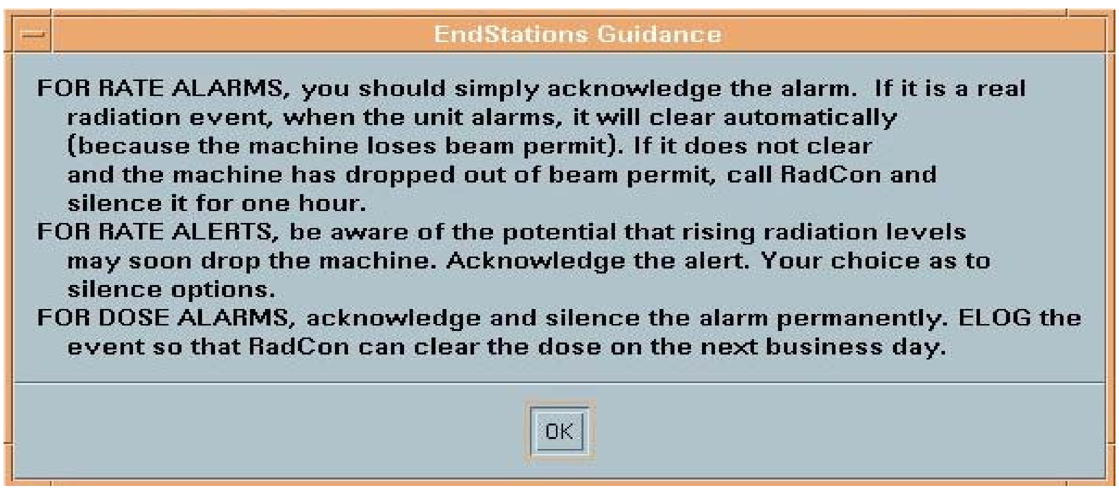
Monitor view – ADM-610



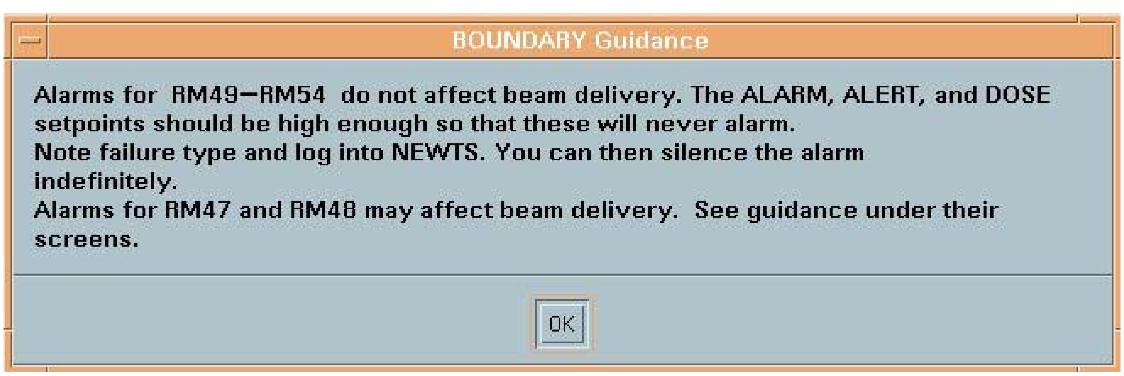
Monitor view – ADM-616



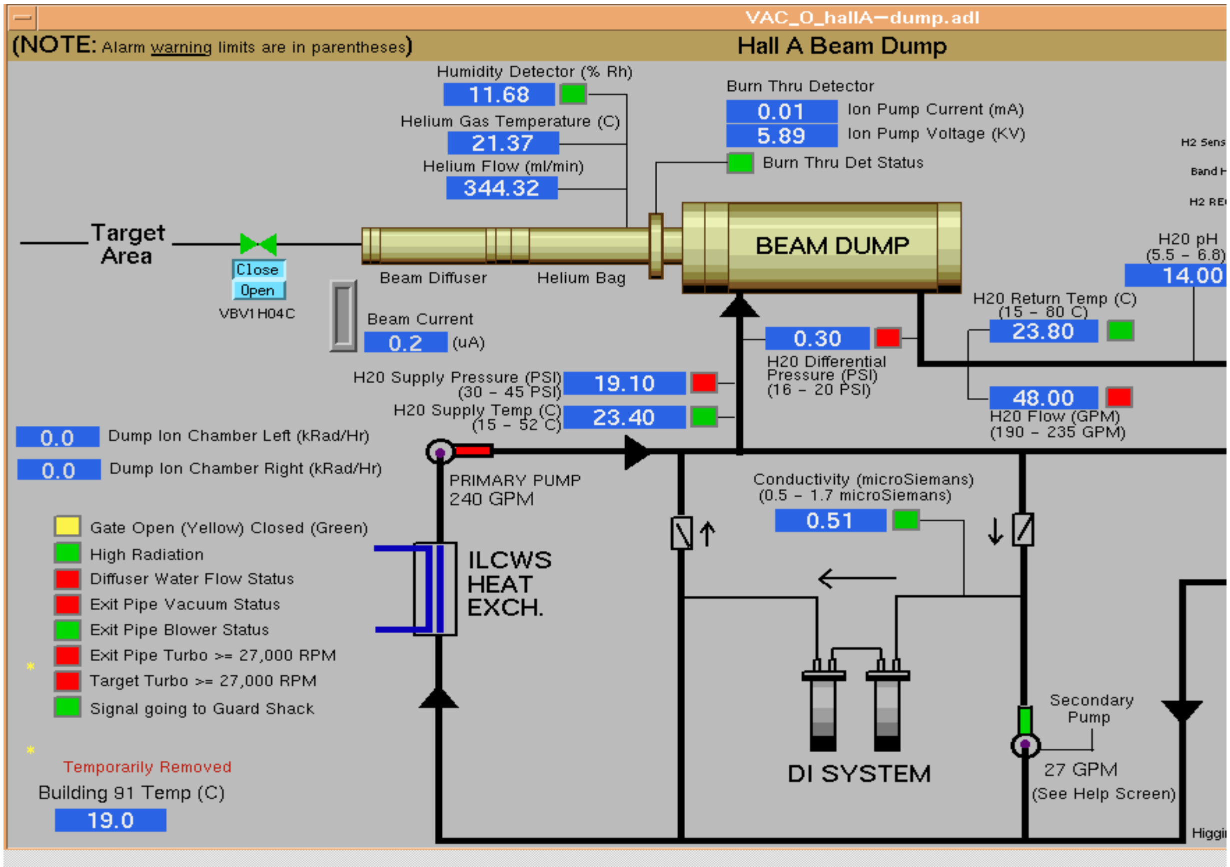
Alarm Handler with standard CARM guidance displayed



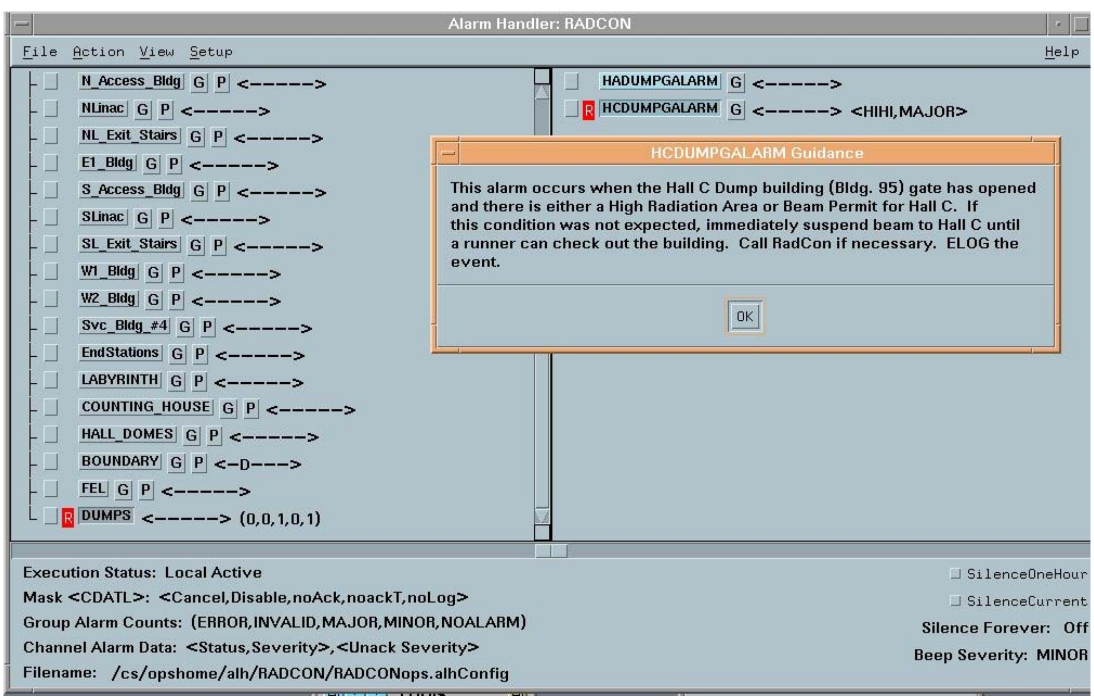
Standard CARM guidance



Boundary monitor guidance



Beam dump screen



Beam dump building alarm guidance

OTHER RADIATION RELATED ALARMS

Beam dump cooling water building radiation alarms

Monitoring of buildings 91 and 95 is performed with RMS-II remote monitors. These units measure the dose rate at the door leading into the buildings. The units are set for an alarm at 100 mR/hr. Activation of the alarm sends a data bit to the EPICS/MEDM system. The entrance door and the outer gate remain locked at all times during beam operations to the applicable hall. The outer gate also sends status data to the operations system.

An alarm will occur on the Radcon alarm handler under the following conditions.

1. If the applicable hall is in BEAM PERMIT, **and** the outer gate is OPEN
2. If the gate is OPEN **and** the RMS-II is registering an alarm (regardless of machine status)
3. Power loss to the RMS-II or the interlock signal

Note: This system is not part of the PSS, and is not interlocked to trip off the accelerator.

If an alarm occurs, contact the RCG and follow the onscreen guidance in the alarm handler.

Non-Accelerator systems

The VTA and Cry-test caves contain local interlocked PSS systems. Local procedures require notification of Radcon anytime an alarm occurs. Where temporary establishment of interlocked radiation detectors exists, the RCG must be notified when radiation alarms occur.

SPILLS OR LOSS OF CONTROL OF RADIOACTIVE MATERIAL

Take appropriate and responsible actions to protect life, property, and the environment. If there is an injury, THE INJURY SHALL ALWAYS TAKE PRECEDENCE OVER RADIOLOGICAL CONTROLS, to the extent of the potential seriousness of the injury.

Practice SWIM'N

- Stop the spill or activity causing it
- Warn others in the vicinity not to enter or stay where they are
- Isolate the area to the extent practicable to prevent accidental entry
- Minimize your own exposure to the material
- Notify the RCG & the responsible oversight authority (custodian, crew chief, etc.)

BEAM RELATED EXPOSURE ACCIDENTS

Refer to the Radiation Control Emergency Procedure Kept in the MCC

- Terminate the exposure producing activity immediately
- Note operating conditions of the machine at the suspected time of exposure
- If there is obvious injury, give top priority to treatment
- Retain all personnel not injured or providing medical treatment
- Notify the RCG immediately
- Perform a radiation survey on the individual(s) (if possible, place the detector on the abdomen and have the person bend at the waist to surround the detector). Record the reading.
- Retain activated articles of clothing, jewelry, or coins and preserve the identity of the owner.
- Attempt to ascertain the locations and time spent in each location of the affected individuals

Remember that the victim of a direct beam exposure accident would not be a hazard to emergency responders. The victim would not be contaminated, and therefore would not need to be handled with any special protective measures or PPE. Handling body fluids is dealt with by standard medical procedure. There would likely not be any readily detectable radioactivity in body fluids or personal items removed for analysis.

EMERGENCY DOSE GUIDELINES

There is no strict upper limit for activities such as lifesaving. The senior manager in charge during the emergency with input from EH&S and RCG personnel must make judgements that weigh benefits of any action with risks of further injury and the potential for saving and protecting life and health.

If the situation involves a substantial personal risk, volunteers will be selected based on their age, experience with the particular problem and their previous dose.

Refer to section I for specific dose guidelines

OBJECTIVES

1. Describe the proper technique for performing each of the following types of surveys:

   A. Area surveys, including beam enclosure surveys

   B. Entry to areas with suspected high or unknown radiation levels

   C. Item surveys

   D. Personnel contamination surveys

2. Discuss posting requirements normally associated with beam enclosure surveys

3. Describe the requirements for proper survey documentation.

4. Identify typical radiological conditions and examples of unusual conditions in beam enclosure areas and the proper response to discovery of conditions such as unposted High Radiation Areas.

5. Describe the characteristics of Hot Spots at JLab.

THE PURPOSE OF RADIATION SURVEYS

Radiation surveys are a primary tool for ensuring that: (1) personnel do not exceed radiation exposure limits or receive unnecessary exposure, and: (2) the requirements for posting radiological areas and radioactive materials are met. It is vital that proper procedures and techniques be used to ensure the quality and accuracy of the measurements made. Many of these measurements are specifically related to regulatory requirements.

GENERAL PROCEDURES FOR RADIATION SURVEYS

Area Surveys

It is important that the survey instrument be appropriate for the type and energy of the radiation encountered in the area. The general guidance here is intended to meet the needs of most beam enclosure entry and other general area surveys performed by arms. The survey meters that may be appropriate include the Bicron Microrem, FAG Teleprobe, and ADM-300X telescoping meter. The telescoping meters are preferred because of the advantages of audible response and long reach. In some areas, specific instruments may be necessary due to the existence of magnetic fields, or because of specific sensitivity requirements.

Ensure the appropriate pre-use checks are completed. This should include a source check.

If equipped, turn on the instrument's audible function. An audible indication is useful for scanning areas as it will give a more rapid indication of elevated exposure levels than the meter readout, and it frees the user from constant observation of the meter.

When entering an area where radiation levels are unknown and potentially high, enter the area with the instrument on the highest scale (if applicable). Upon entry, stop and move down through the scales until an on-scale reading is obtained. Then proceed on with the survey.

Hold the instrument at approximately waist height, and slowly walk through the area. Periodically move the instrument (or detector) vertically between the knee and head level. Unless the actual source of radiation is well known, stop and execute a full turn periodically to ensure the body is not shielding a radiation source. This is not usually necessary for beam enclosure surveys.

- For beam enclosure surveys, pay particular attention to:
  - Checking ALL beamline passes that have had beam present in them.
  - Areas where there are abrupt changes in the beam path
  - Any known areas of scraping or beam loss.
  - Surveys on magnets (esp. strong permanent magnets eg. Ion packs) - the magnetic field will affect some instruments
  - Any area on a beamline that has been discolored by beam scraping
  - Contact dose rates above 100 mrem/hr.
  - Potential shielding of Hot Spots by magnets and other components or shielding
  - Possible streaming of radiation from behind shielded areas or tunnels, tubes, ducts

- For surveys in Controlled Areas where radioactive material is stored, pay attention to:
    - Any potential movement of material which may have affected the boundary
    - The proper labeling of materials within the area
- For all surveys watch for:
    - The presence of radiation levels which would require a different posting or movement, modification or addition to a boundary.
    - The presence of radiation levels which require more stringent administrative controls such as an RWP.
    - Streaming of radiation through gaps in shielding

Material Release Surveys

ARMs are NOT authorized to release potentially radioactive material from the Radiologically Controlled Area. This automatically includes any trash from the beam enclosure, and any other item present in an area which has seen an activating field. There are a few exceptions to release surveys for certain beam enclosure areas. These will be covered shortly.

ARMs may conduct surveys on items for purposes of relocating the item from the beam enclosure to a specifically designated staging area for subsequent release survey by RCG personnel.

- Any item which has potential for contamination (removed from known contaminated system or there is suspected contamination based on knowledge of process) must not be relocated from the RCA. The RCG should be notified immediately upon discovery of a potentially contaminated item outside a posted Contamination Area.
- An item being relocated to the interim storage area should be tagged with a radioactive material tag if it is measurably radioactive. These tags should be available in the storage area. The RCG should be notified as soon as practicable in order to account for the item in inventory.
- If the dose rate from an item being relocated is over 100 mrem/hr on contact, or produces a Radiation Area (> 5 mrem/hr at 30 cm), the RCG should be notified immediately.
- **Always check the radiation levels at the boundary to the storage area to ensure that the addition of an item has not changed the boundary delineation.**

Self Monitoring

The technique for personnel contamination surveys is similar to that for surveying any other surface, however, a standard procedure ensures that particular attention is paid to critical areas and that areas are not likely to be overlooked.

- Verify the instrument is on, set to the lowest scale, and the audible can be heard.

- Survey the hands before picking up or touching the probe

- Hold the probe within 1/2" of the surface of the body and move the probe slowly over the surface at ~1" per second.

- Proceed to survey the entire body in the following typical order

  Head - pause at the mouth and nose for approximately 5 seconds
  Neck and shoulders
  Arms - pause at the elbows
  Chest and abdomen
  Back, hips and seat of pants - check closely if you have been seated in the area
  Legs - pausing at the knees
  Tops of shoes
  Bottoms of shoes - usually done while stepping onto a step-off pad
  Any personal items - pens pencils, dosimetry

- The whole body should take at least 2-3 minutes.

- If the audible count rate increases, pause for 5-10 seconds over the area to give time for instrument response.

Survey Documentation

It is important that surveys done for purposes of radiation protection be documented correctly. In effect, if you do not document a survey, it was not performed. Important types of surveys which ARMs perform that require documentation include:

- Surveys for entry into beam enclosure following operation of beam

- Surveys performed in conjunction with posting radiological areas and verifying boundaries

- Surveys performed for purposes of de-posting or down-grading of postings

The scope of the initial entry survey performed by an ARM is to identify work area radiation levels and the presence of any areas exceeding existing posting levels or that might require additional controls to those present. These surveys are appropriate for entries to perform routine diagnostic evaluations or equipment repair in the enclosure. They should not be used as the basis for controlling complex radiological work.

Typical Conditions associated with accelerator operation

For areas accessible in beam enclosures after shutdown, typical areas where Radiation, High Radiation or Very High Radiation Areas may occur include:

- In the vicinity of a beam dump, target chamber, and intermediate beamline
- In the vicinity of any point of significant beam loss (Hot Spots)
- Near closed-loop beam dump cooling water systems after beam shut off (eg. BSY)
- In general, the following beam enclosure areas (when accessible)
    - Extraction region (YA, YB magnets)
    - Spreader/recombiner regions
    - Beam switchyard
    - Extracted beam transport channels
    - End station target chamber
    - End station dump entrance transition area

Note: End station conditions apply to halls A and C only

Other areas with potential for significant dose rates.

- Near operating accelerator components such as cavities, electron guns, etc.
- Above unshielded penetrations, equipment hatch covers, end station roof during operations
- In beam dump cooling water buildings
  - Very high levels present when beam is on
  - Radiation or High Radiation Area when beam is off

Areas or items with potential for contamination

- Leaks and spills from contaminated systems (dumps, radiators, diffusers, condensate)
- Internals of air handling equipment operating inside the enclosure
- On hot spots
- On and near target chambers and the immediate downstream beamline
- End station dump entrance transition area (as well as in dump tunnel)
- During some conditions of operation, inside electronic racks, on electrically charged surfaces, or potentially, in general areas of the end stations

Hot Spots

Beamline Hot Spots tend to be VERY small, intense sources, approaching point-source geometry. The inverse square relationship causes dose rates to be relatively low at a distance of 1-2 meters. This can be misleading. For example:

> If you are 2m from the beamline and measure a dose rate of 1 mrem/hr, assuming al the radiation is coming from a small point source, the contact dose rate is in excess of 10 rem/hr.

* In practice, the relationship between whole body and contact dose rates on Hot Spots tends to be on the order of a factor of ten.

A Hot Spot may be present when the whole body dose rate is below the criteria for posting a Radiation Area. Follow the guidance below to ensure your survey is sensitive to this. Hot Spots occurring due to significant beam loss may exhibit signs of heating. This results in vaporized metal on the surface – a surface contamination issue. Contamination may be present even when no visible signs of heating occur. Follow rules of thumb below.

Do not allow hands on work on Hot Spots without RCG concurrence. Note Hot Spots on the survey sheet.

Basic Survey Requirements

The following requirements are the "default" for performing surveys upon entry to the enclosure. Specific exceptions to these requirements are discussed in the following sections.

Level of detail

The minimum level of 'resolution' for a survey is normally "Whole Body". The survey must be able to provide answers to the questions: (1) What is the maximum whole body dose rate?, (2) What is the proper designation for area posting?

When to get contact dose rates

Scenarios:

(1) Areas not meeting the definition of Radiation or High Rad Areas: Take contact readings when WB dose rates are > about 2 mrem/hr.
(2) Within Radiation/High Rad Area: After finding the maximum WB dose rate, identify the spot and the contact reading associated with it.

Limitations:

High Radiation Areas:
You may not enter any posted HRA or any area you discover with WB dose rates > 100 mrem/hr. If continuation of the survey requires entry to any such area, you must stop and get assistance from the RCG. Most beam enclosure High Rad Areas are small enough to be surveyed adequately from outside the boundary.

Radiation Areas
You may enter radiation areas to perform surveys, in accordance with the ARM survey RWP. But in many cases, it is not necessary. Keep ALARA in mind.

Contamination Areas
Do not enter any area posted as a contamination area to perform surveys. If you cannot get the required survey data from outside the area, call the RCG for assistance. Many contamination areas will be contiguous with Radiation or High Rad Areas.

In addition to the beamline itself, remember to obtain general area dose rates, and check boundaries to posted areas to verify the placement of the boundary.

Ask the following questions:

Are the dose rates at boundaries appropriate to the type of boundary?
Is there any area that meets a posting trigger that is not posted?

For the contact dose rates, consider:
- Is a Hot Spot posting required?
- Does the reading suggest the presence of contamination?
- Does the reading suggest the presence of a Rad/High Rad area which you have not already identified?

Rules of thumb to help with this are:

Radiation Area is likely if contact dose rate > 150 mR/hr
- Contamination is probable if contact dose rate > 250 mR/hr
- High Rad Area is possible if contact dose rate > 500 mR/hr

When you have gathered all the necessary data and determined that boundaries are correctly placed with appropriate postings, you are free to allow general access to the enclosure.

When to call Radcon:

- Presence of a "new" High Radiation Area (not previously posted)
- Presence of a High Radiation Area with WB dose rate > 1 rem/hr
- Potential for contamination where no contamination area is posted
- People need access to Radiation\High Rad Areas, or Contamination Areas

Information Required on the Survey Sheet

- Your name, date, time of survey, instrument used, calibration due date.
- Accelerator conditions prior to shutdown.
- Reason for the survey - Examples: Reboot computer, Check target vacuum, Open for maintenance day.
- Units - i.e. mR/hr
- Type of measurement - i.e. contact, WB, or GA. A legend that explains both units and type of reading is preferred. Each survey data point on the sheet should be identifiable as to the nature of the reading.
- Boundaries - All boundaries should be indicated on the map, AND the type of posting on the boundary. Boundary dose rates should be shown that confirm the proper placement of the boundary.
- During partial survey situations (see below for applicability), indicate areas people entered, WB and contact dose rates in the work areas, and note specifically that the work party had continuous ARM surveillance.
- Type of survey – initial entry, partial or complete survey, etc.

Exceptions to the Default Method

Normally the surveyor(s) enters alone first and surveys the area, then when (s)he is satisfied that conditions are acceptable to general entry, contacts the SSO to allow access.

The only exceptions to this are when you:

(A) "Partial survey" - directly escort the work party to the work location, and remain in the area
(B) "Post exclusion zones" - post barriers to areas that have not been surveyed, and ensure that the accessible area is thoroughly surveyed and properly posted as described above (if not remaining in the area)

When option (A) is used, you should provide radiological information to the work crew - if a Hot Spot or Radiation Area exists in the work area, you must make sure that the worker(s) know the extent of the area and what the levels are. Refer to the RWP trigger values, and call the RCG if there is any question as to the need for an RWP. Do not allow direct hands-on work on a Hot Spot without RCG concurrence. The partial survey must be noted as such on the survey sheet. When this option is used, once the ARM and work party leave, ANY SUBSEQUENT ENTRY TO THE AREA REQUIRES ANOTHER SURVEY.

If option (B) is used, the barriers posted must be shown on the survey sheet along with any other posted areas. Once the survey and posting is complete, unescorted entries are allowed. This method is restricted to the CEBAF accelerator tunnels and FEL only. Postings should read, Danger, Do not enter, This area has not been surveyed. **If process knowledge suggests that high radiation areas may exist in the unsurveyed area (known high beam loss, vacuum event, etc.), do not use this option.**

OPTION (A) IS PREFERRED WHEN A FULL SURVEY IS NOT PERFORMED

Disposition of Survey Forms

When completed, all original survey forms should be routed to the MCC. It is a good practice to also keep a copy available in the applicable counting room (for hall surveys) or FEL control room, or to post a copy at the entrance, especially if a long access is foreseen; the radiological information should be available to anyone entering the area.

Area-Specific Items

Hall A and C are generally comparable, and the requirements for survey are the same there. Expect Radiation Areas at the targets and dumps. During high power operations (> 50 uA) these often become High Radiation Areas. Assume that the beamline downstream of the target chamber is contaminated for the first two or three meters. Do not allow direct handling of this portion of the beamline even if the area is not posted as a Contamination Area - ALWAYS GET RCG CONCURRENCE for work in this area. As the WB dose rate at the target increases, there is increased probablility that the pivot is contaminated. As a rule of thumb, if the dose rate at the target/exit area is high enough to trigger an RWP, assume there is a need for evaluations of surface contamination on the chamber, pivot, and immediate surrounding areas (this is conservative, but useful).

In hall B, there is no reason to suspect any surface contamination problems. Air activation is negligible, so air handling equipment is not a concern as in other areas. There are no sources of contaminated water in hall B. Hall B has an "exemption" from the normal item release survey requirements. If an item coming out of the hall was associated with the actual beamline (including mechanical support hardware), then it requires a survey. If it is support equipment (computers, dewars, tools, parts, etc.) which was not directly associated with the beamline (and not within 1 meter of the beam line), it does not require a survey. Of course, in the other halls, ALL items of ANY kind that were in the hall during beam ops need a survey (RCG may allow removal of some items on a case basis for subsequent survey based on process knowledge).

Default Postings For Injector, Hall B and FEL
Due to typically low levels of activation in hall B and the FEL, and no expectation of activation in the CEBAF injector, the radiological designation of these areas may change with access conditions. These areas are considered RCAs during Controlled Access (just as any other enclosure area), but may be de-posted conditionally afterward.

Injector -- The posting designation drops automatically to non-RCA (defaulting to Controlled Area) when the state changes to Restricted Access. No survey is needed for this designation change.

Hall B and the FEL both require a full survey to change status to Restricted Access.

Hall B -- Normally the designation drops to non-RCA (defaulting to Controlled Area) when the status is changed to Restricted Access. **To meet this posting level, your survey must be sensitive enough to verify that the whole body dose rate is less than the RCA trigger – 0.05 mrem/hr. This is best done with a Bicron Micro-rem** (Teleprobe instruments do not have the needed precision at that dose rate). Postings at the entrance denote this "dual" designation. The hall remains posted as a Radioactive Material Area. There are typically "pockets" of RCAs within the hall that are roped off and specifically posted.

FEL – The major difference in Hall B and FEL is that the designation does not automatically change to non-RCA when there is an access state change. A full survey is required to change to Restricted Access, and the ARM is authorized to do the survey. But an RCT must authorize the radiological designation change. See the requirements on the next page for FEL Rapid Access Conditions.

Rapid Access systems - General

There are “rapid access” systems present in the CEBAF injector, Hall B and FEL. These systems use a network of area detectors that feed back to a central monitor. If the dose rate is below the trip point on all detectors, Controlled Access is allowed without a specific survey of the area. When using the rapid access method of entry, the SSO instructs the initial entrant to functionally test the beacon at the entry point. In hall B and FEL, persons entering are instructed that they are not permitted to perform hands on activities on beamline or target components without a survey (ARMs are permitted to conduct this survey). There is no requirement for this in the injector, because there is no beamline activation in the injector.

FEL Rapid Access Conditions

1. Only **RCTs** may reduce the posting level of the vault to **non-RCA**. This will be done for maintenance periods lasting **three work days or more or if authorized by the RCM**. Otherwise the vault will remain posted as an RCA/dosimetry required.

2. The region west of the last crossover “bridge” (enclosing dump area as well as a section of the third cryomodule) will be “semi permanently” posted as “Danger, do not enter, potential high radiation area, this area has not been surveyed” or words to that effect.

3. ARMs may survey and de-post the aforementioned HRA if extended access needs exist, or they may provide partial surveys for incidental entries during controlled accesses.

4. If the aforementioned “potential HRA” is de-posted in accordance with the above, it is the responsibility of FEL operations staff to replace the boundary/postings prior to operations. This will be documented on the Pre-operational checklist **(to be performed by FEL operations personnel vice RCG personnel.)**

5. Controlled Accesses may be conducted without surveys provided the Rapid Access System beacon is not illuminated**.** **NOTE**: Operability of the system must be verified during first entry by depressing the “test” button.

6. Any hands-on beamline work during Controlled Access requires a survey of the area(s) affected.

7. Changing state to **Restricted Access** requires a **full survey of the vault.**
   NOTE: The state change does **NOT** automatically invoke a posting reduction. **(See item 1.)**

8. RCT weekly survey for 3 months to verify functionality of the system (i.e., there are no radiation areas “undetected” by the Rapid Access System.)

9. Violation of the Rapid Access System (i.e., entry into the FEL **without a survey when a probe is alarming/flashing**) will result in loss of the Rapid Access System.

Hold Points

The following conditions require notification of Radcon:

- Discovery of a High Radiation Area that was not previously posted (includes an area that has grown in size, or grown from a Radiation Area to a High Radiation Area).
- Discovery of an area with whole body dose rate > 1000 mrem/hr
- Any conditions that indicate the presence of contamination in the work area
- Any work requiring access to a Radiation Area (or higher)
- Hands-on work on a Hot Spot

When to post

When a partial survey/escorted access is conducted:

- Posting of areas and Hot Spots is not required **IF**:
  - You inform all personnel in the area of the existence of the area and the levels found
  - No one will be working in the area or on the Hot Spot
  - You can adequately ensure control of the area and prevent uninformed entry (i.e. through direct surveillance and access control through the SSO)

  Note: All areas should be noted on the survey map, along with adequate notations regarding type and location of work, and any administrative controls/Radcon concurrence, etc.

When a full survey is conducted (for Controlled or Restricted Access):

- Post any Radiation Areas and call the RCG for guidance if necessary
- Verify Radiation and High Radiation Area boundary conditions
- Post Hot Spots if they exist outside the boundary of a posted area
- Do not drop to restricted access if there are unposted areas

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References for Unit 5

1. TJNAF Radiological Control Manual, May 24, 1999

2. DOE Standardized Training for Radiological Control Technologists

3. 10CFR835, Occupational Radiation Protection